A Supply Chain Model at the Strategic Level

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Un modèle de chaîne d'approvisionnement au niveau stratégique

Une optimisation utilisant le recuit simulé

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Résumé

Dans ce papier, nous introduisons la notion de modèle d'une chaîne d'approvisionnement au niveau stratégique. A ce niveau, une chaîne d'approvisionnement est toujours composée de cinq activités de base qui sont "Acheter" , "Faire" , "Transporter", "Stocker" et "Vendre" . nous montrons comment optimiser la chaîne d'approvisionnement au niveau stratégique.

Mots clefs : Chaîne d'approvisionnement, gestion stratégique, recuit simulé

A supply chain model at the strategic level

Optimization based on simulated annealing

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Abstract

In this paper, we introduce the notion of strategic model of supply chain. At the strategic level, a supply chain is always composed of five basic activities, denoted by Buy, Make, Move, Store and Sell. We present a specific model and show how to optimize the related supply chain from a strategic point of view.

Keywords: Supply chain, Optimization, Strategic management, Simulated annealing

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1. Introduction

Supply chain management is considered to achieve a more cost effective satisfaction of customer requirement through buyer-supplier process integration (Christoper, 92). It is a global network of organizations that cooperate to improve the flows of material and information among suppliers, customers and other participating organizations. In the present scenario, the products are part of global market where lots of companies are trying to get the market share. So, it is essential to provide the required product at right time, at right place, in right quantity, with improved quality and competitive prices to maintain and strengthen the position in the market. The above features could only be achieved by the proper coordination of all the participating organizations. At the strategic level these organization activities can be divided into five major categories also known as key activities of supply chain management, that are "Buy", "Make", "Move", "Store" and "Sell".

The "Buy" activity includes all the activities that concern the acquisition of raw material and components. For instance, selection of providers, quality test of raw material, management of employees who are in charge of buying raw material and components, belong to the "Buy" activity.

The "Make" activity concerns product manufacturing; this involves performing operations, quality control, employee training, scheduling and rework, to quote only a few.

The "Move" activity concerns all the transportation activities and the related management activities. It may include transportation from providers to manufacturing units, from manufacturing units to retailers and from retailers to customers, as well as the transportation inside the manufacturing units. The contents of the "Move" activity depends upon the limits of the supply chain under consideration.

The "Store" activity includes all the storage activities, from raw material and component to finished products.

Finally, the "Sell" activity includes the commercial activities like marketing, after-sell service, etc.

Strategic decisions can be made in each of the five activities listed above. Any such decision influences the other activities. Modeling a supply chain consists in modeling each one of the supply chain activities as well as the mechanism that disseminate strategic decisions among all the activities. S.Selçuk, N.C. Simpson and Asoo Vakharia (S. Selçuk 99) identified several "decision that need to be considered in jointly optimizing production/distribution planning. Some of those that are to be considered at strategic level are listed below.

- How are the supplier selected? What criteria are used in the selection of suppliers?

- How many suppliers for each category or set of materials should there be?
- What is the volume and frequency of shipments from each supplier?
- What kind of relationship should be established with each supplier?
- Where should transformation process be located? Does the flow of inventory from feeder plants cross-organizational boundaries?
- What is the amount of inventory of each product that should be maintained at each distributor?
- How many distribution centers should be operated? Where should be they located? What is the aggregate capacity of each center? "

In this paper we propose the strategic model of a specific Supply chain. The proposed integrated problem is a combinatorial optimization problem, involving concave. Simulated annealing (SA) is used to reach a near optimal solution to the global problem.

SA has been applied to many NP-Complete problems. Golden and skiscim (1986) used SA to solve routing and location problem. Heraguand Alfa (1992) applied SA to the layout problem. The tabu search (Glover, 1989,1990) and a genetic algorithm (Goldberg, 1989) have been shown to be good for solving combinatorial optimization problem and could be applicable to this problem and concave cost optimization problems. It is suggested for future research.

We present the problem description and mathematical formulation of all five activities in section 2 and connections between these activities in section 3. Section 4 shows how to utilize simulated annealing to reach a near optimal, if not optimal, solution. Section 5 presents a numerical example. Section 6 is the conclusion.

2. Problem description

We consider the case of a new product type that is to be distributed in different regions. Each region has several retailers that are in charge of selling the products. The production is made on a Just-In-Time basis. As a consequence, the only storage facilities available in the supply chain are at the retailer level ("Store "activity). The "Move" activity concerns only the transportation of products from manufacturing units to retailers, as well as the transportation of semi-finished products inside the manufacturing units. The "Make" activity is performed in the manufacturing unit at a certain cost that depends on the quantity produced and the manufacturing unit in charge of the production. As we will see hereafter, the production of a manufacturing unit is lower and upper bounded. Raw material and the components are send to the manufacturing units by providers. The transportation is under the responsibilities of the providers and its cost is included in the cost of the material. The "Buy" activity is limited to the selection of the providers. The "Sell" activity concerns the choice of the quantity to be sold by each one of the retailers.

The model presented hereafter focuses on the strategic perspective of the supply chain. The goal is to provide a tool that will help the managers to decide if the project is profitable to the participating organizations. The project horizon is decided by the management or is the shortest horizon by which management want recover all the investment, also known as return on investment (ROI).

In the remaining of this section, we will present these activities in details and propose the mathematical formulation of each of them for a specific project.

2.1 Buy activity

The prime objective of this activity is the selection of providers that can satisfy the demand of manufacturing units economically in the project horizon. Each provider cannot provide less than a given quantity and more than an upper given quantity. The cost incurred when a provider delivers a given quantity of raw material to a manufacturing unit is a concave function of the quantity and depends upon the pair (provider, manufacturing unit) under consideration.

Let us formalize the model of "Buy" activity.

A set of providers $N=\{1,2...n\}$ can deliver raw material to a set of manufacturing units $M=\{1,2...m\}$. The quantity to be delivered to every manufacturing unit $k \in M$ during specific period (say a week) is Ω_k. There are two constraints that apply to any provider $i \in N$, that is:

-The minimum quantity the provider i is prepared to deliver to any manufacturing unit $k \in M$ is fixed and denoted by m_{ik}.

-The maximum quantity the provider $i \in N$ is able to deliver is fixed by the provider and denoted by M_i.

The manufacturing cost $a_{ik}(x_{ik})$ is a concave function of x_{ik}, where x_{ik} is the quantity purchased from provider $i \in N$ by manufacturing unit $k \in M$. It can be expressed as:

$$a_{ij}(x_{ik}) = \begin{cases} 0 & \text{if } x_{ik} = 0 \\ b_{ik} + c_{ik}(x_{ik}) & \text{if } x_{ik} > 0 \end{cases},$$

where $b_{ik} \geq 0$, $c_{ik}(x_{ik})$ is a concave, continuous increasing function, and $\underset{x \to 0^+}{Lim}\, c_{ik} = 0$. Finally, the problem to be solved can be formulated as follows.

$$\text{Min } Z = \sum_{i=1}^{n} \sum_{k=1}^{m} a_{ik}(x_{ik}) \tag{1}$$

s.t.

$$\sum_{i=1}^{n} x_{ik} = \Omega_k \ , \quad k \in M \tag{2}$$

$$\sum_{k=1}^{m} x_{ik} \leq M_i \ , \ i \in N \tag{3}$$

$$x_{ik} \in \{0\} \cup [m_{ik}, M_i] \text{ for } i \in N, k \in M \tag{4}$$

This problem concerns an elementary period (a week or month).In the above formulation, constraint 2 shows that the total quantity received by each manufacturing unit is equal to the quantity required by the manufacturing unit. Constraints 3 guaranties that the total quantity delivered by any particular provider is less than or equal to its maximum capacity. Constraint 4 shows that the provider either does not provide anything or provides quantity that lies between the minimal and maximal limit.

Let T be the project horizon and α the discount rate, then the total investment during the project horizon is given by

$$\text{CB}(i = 1,..n; k = 1,..m) = \frac{(1+\alpha)^{T+1} - (1+\alpha)}{\alpha} \sum_{i=1}^{n} \sum_{k=1}^{m} a_{ik}(x_{ik}) \tag{5}$$

2.2 Store activity

The product demand is always considered as random variable. At the retailer level, inventories are used for facing the randomness of demand. The objective of this activity is to decide the target inventory level for each retailer. The target inventory level reflect a trade-off between storage cost and stock run out cost. The average demand is known and denoted by

$\overline{d_i}$, where $i = 1,2,..,r$, r being the number of regions. The average demand of retailer j of region i is denoted by $\overline{d_{ij}}$, where $j=1,2,..z_i$, where z_i is the number of retailers in region i. Indeed,

$$\sum_{j=1}^{z_i} \overline{d_{ij}} = \overline{d_i} \quad \text{for } i = 1,2,..r. \tag{6}$$

σ_{ij} is the standard deviation of the retailer demand. We assume that,

$$\sum_{j=1}^{z_i} \sigma_{ij}^2 = \sigma_i^2 \ , \quad i = 1,2,..,r$$

σ_i^2 is given and constant. Furthermore,

$$\sigma_{ij} = \sigma_i \sqrt{\frac{\overline{d_{ij}}}{\overline{d_i}}} \tag{7}$$

As soon as the values $\overline{d_{ij}}$ are chosen according to constraints (6), the random variable d_{ij} could be computed. We then define the target inventory level by minimizing criterion (8), where v_{ij} is the storing and handling cost of finished item and h_{ij} the lost sell per unit.

$$CS_{ij}(Y_{ij},1) = \frac{v_{ij}}{\sigma_{ij}\sqrt{2\pi}} \int_{d_{ij}=0}^{Y_{ij}} \exp\left[-\frac{1}{2}\left(\frac{d_{ij}-\overline{d_{ij}}}{\sigma_{ij}}\right)^2\right](Y_{ij}-d_{ij})d(d_{ij})$$

$$+\frac{h_{ij}}{\sigma_{ij}\sqrt{2\pi}} \int_{d_{ij}=Y_{ij}}^{+\infty} \exp\left[-\frac{1}{2}\left(\frac{d_{ij}-\overline{d_{ij}}}{\sigma_{ij}}\right)^2\right](d_{ij}-Y_{ij})d(d_{ij}) \tag{8}$$

First right hand side part of the equation (8) shows the expected storing cost and the second right hand side part shows the expected lost sell, if the target quantity is Y_{ij}.

Assuming that all the safety stocks Y_{ij} are given, the average total running cost during one elementary period is given by,

$$CS\left(\{y_{ij}\}_{i=1,2,..r;j=1,2,...,z_i}\right)=\sum_{i=1}^{r}\sum_{j=1}^{z_i}CS_{ij}(y_{ij},1) \tag{9}$$

Finally, the total expected cost over the horizon T is:

$$CS\left(\{y_{ij}\}_{i=1,2,..r;j=1,2,...,z_i},T\right)=\frac{(1+\alpha)^{T+1}-(1+\alpha)}{\alpha}\sum_{i=1}^{r}\sum_{j=1}^{z_i}CS_{ij}(y_{ij},1) \tag{10}$$

2.3 Make activity

The "Make" activity is in charge of transforming raw material and components into finished products. This activity can be performed by anyone of the available manufacturing units. In each manufacturing unit, G types of resources are available and each type is necessary to manufacture products.

We have to select the manufacturing units to be used and the quantities to be produced by each of them during each elementary period. While selecting manufacturing units, we can use the remaining capacity of each type of resources to perform the new products, but this capacity may be not sufficient to perform the targeted production. In this case, we have to buy additional resources. The decision of buying new resources also belongs to solution of the problem.

Let $k=1,2,..,m$ be the manufacturing units that are available for the current project. Available idle capacity is known for every resource type $g=1,2,..,G$. Capacity $\varphi^0_{k,g}$, $g\in\{1,2,..,G\}$ is the capacity available in manufacturing unit k for resources of type g. Operation cost per unit on resource type g in manufacturing unit k is denoted by λ_{kg}. The number of jobs that could be processed by a resource of type g in manufacturing unit k during one elementary period is ω_{kg}. The purchasing cost of a new resource of type g in unit k is Λ_{kg}. The maximum production is restricted for every manufacturing unit k by p_k.

The total production cost and initial investment for new resources is given by:

$$MAN(\{\Omega_k\}k=1,...,m,T)=(1+\alpha)^T\sum_{k=1}^{m}\sum_{g=1}^{G}\lambda_{kg}.\Omega_k$$

$$+\frac{(1+\alpha)^{T+1}-(1+\alpha)}{\alpha}\sum_{k=1}^{m}\sum_{g=1}^{G}\Delta_{kg}\left\lceil\frac{\Omega_k-\varphi^0_{kg}}{\omega_{kg}}\right\rceil \tag{11}$$

Subjected to

$$\sum_{k=1}^{m}\Omega_k \le p_k \text{ for } k = 1,2,\ldots,m \tag{12}$$

$$\sum_{k=1}^{m}\Omega_k = \sum_{i=1}^{r}\overline{d_i} \tag{13}$$

The first part of right side of equation (11) shows the processing cost and second part shows the investment in new resources. Constraint (12) shows that the total production of manufacturing unit is upper bounded. Constraint (13) shows that the total production of all selected units is equal to the total average demand of all regions.

2.4 Move activity

"Move" concerns the transportation of products. Broadly, we could say that any movement of material comes under "Move" activity. In this model we only concentrate on the transportation of products between manufacturing units and retailers. At the strategic level of "Move" activity, the objective is to:

- Utilize the available resources and,
- Purchase the new vehicles, if transportation capacity is lacking in any region.

The optimal utilization of resources and buying decisions depend upon the selected set of manufacturing units, the quantity to be shipped and the available transportation capacity in each region. We assume linear transportation costs for the supply chain model under consideration.

Let q_{kij} be the quantity delivered to j^{th} retailer of i^{th} region from k^{th} manufacturing unit during one elementary period. The available transportation capacity from manufacturing unit k to retailer j of region i is denoted by q_{kij}^0 . The transportation cost per unit quantity is denoted by c_{kij}. The transportation capacity of a vehicle is denoted by KT. We assume that this capacity is same in every region. The cost of a new vehicle is expressed by C_r where r is the index of the region.

The total cost incurred in a given project horizon is given by the following expression,

$$CM = (1+\alpha)^T \sum_{k=1}^{m}\sum_{i=1}^{r}\sum_{j=1}^{z_i} C_r \left\lceil \frac{q_{kij} - q_{kij}^0}{KT} \right\rceil$$

$$+\frac{(1+\alpha)^{T+1}-(1+\alpha)}{\alpha}\sum_{k=1}^{m}\sum_{i=1}^{r}\sum_{j=1}^{z_i}c_{kij}\cdot q_{kij} \tag{14}$$

First right side part of the above expression (14) denotes the total investment for buying new vehicles, if needed. The second part shows the transportation cost for shipping the goods.

2.5 Sell activity

In the presented model, the goal of the "Sell" activity is to evaluate the expected revenue in each elementary period. The decision of executing the project or not is only based upon the expected revenue in the planned project horizon: if the revenue exceeds substantially the sum of the expenses of all activities, the project will be approved.

In this model we consider the market that is divided into various regions, say $i=1,2,..,r$. Furthermore, every region is operated by several retailers say, $j=1,2,..z_i$ .for region i. The average demand of each region is denoted by $\overline{d_i}$, where $i=1,2,..,r$, and the average demand of each retailer is denoted by $\overline{d_{ij}}$. Standard deviation of demand in each region is known and denoted by σ_i and the standard deviation of retailer is denoted by σ_{ij} (Refer to equation 6 and 7)

Assume that the per unit benefit made by retailer j in region i is b_{ij}. Then the total expected benefit made by all retailers in all region during project horizon T is expressed in equation (15),

$$BN(T)=\frac{(1+\alpha)^{T}-(1+\alpha)}{\alpha}\sum_{i=1}^{r}\sum_{j=1}^{z_i}b_{ij}\overline{d_{ij}} \tag{15}$$

3 Relation between the activities

The connection between the five activities in the project considered in the paper is represented in Figure 1. As we can see:

- The inputs of the "Sell" and "Make" activities are known: they are the average demands in the regions for each elementary period. We assume that the average demand in region i for each elementary period $\overline{d_i}$. We assume that these average demands are steady during project horizon.

- The output of "Sell" activity is the selling objectives of the retailers. These objectives are the inputs of "Store" and "Move" activities.
- The second type of inputs of the "Move" activity is the outputs of "Make" activity, that is the production of each one of the manufacturing units.
- The only input to "Buy" activity is the output of "Make" activity.

We see that there are two levels in the activities of this model. At the highest level, we find the "Sell" and "Make" activities, the outputs of which feeds the other activities. Thus, as soon as the outputs of these two activities are known, we can optimize the other activities. Furthermore, "Sell" activity is steady and independent from "Make" activity. So, as soon as the output of "Sell" is decided, we could manipulate the "Make" activity in search of global solution. Considering above remarks, the solution of the problem using simulated annealing is straight forward, as explained in the next section.

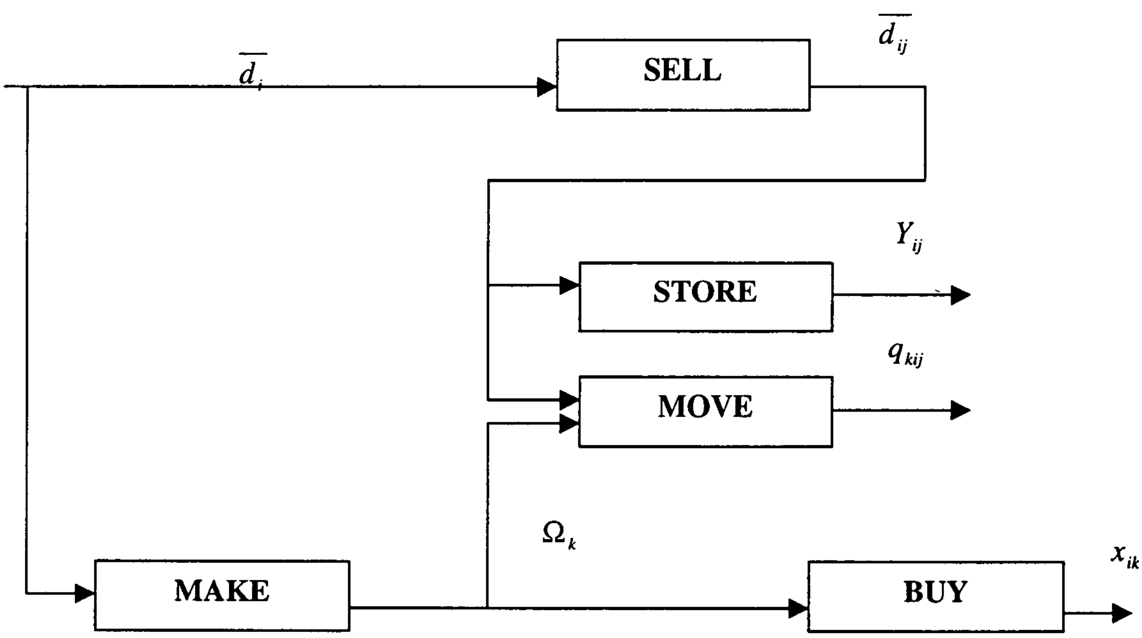

Fig. 1 Relation between the activities

4. Solution method based on simulated annealing (SA)

In this section, we first show the approach to generate initial feasible solution: We then show the method to reach the neighbor solution. Finally, we present the SA algorithm and its application in our problem.

4.1 IFS (Initial feasible solution)

Simulated annealing is the stochastic optimization algorithm that starts with initial feasible solution and continuous searches for better solution. The method is as follows:

1.Compute net demand $D=\sum_{k=1}^{r}\overline{d_i}$

It is the net demand of all regions.

2. Set $\Omega_k = 0$, where k=1,2,..m

We set the production of all manufacturing units to zero. m represent the total number of manufacturing units.

3. Set k=1
4. If (D=0) then Stop.
5. Set $\Omega_k = min\ (p_k, D)$
6. Set D=D-Ω_k
7. Set k=k+1
8. If (k>m) then Stop (No solution)

It shows that the total demand is greater than the net production of all manufacturing units.

9. Go to 1

Initial solution is the any feasible solution that satisfies all the applied constraints .In our case the only constraints with manufacturing unit is its upper production capacity.

4.2 Neighborhood solution (NS)

The method for locating the neighbor solution is as follows:

We assume that $\Omega_k < p_k$ and $\Omega_k < p_k$ for at least two manufacturing unit k_1 and k_2 otherwise it is impossible to find the neighborhood solution.

1. Generate a random number R between 0 to 1.
2. If R<0.5 go to 9

We choose "Make" and "Sell" activity with probability 0.5 for searching neighborhood solution

3. Generate randomly *MU1* such that $\Omega_{MU1} < p_{MU1}$.
4. Generate randomly *MU2* such that $\Omega_{MU2} = 0$.
5. If (*MU1=MU2*) go to 1
6. Set $\Omega_{MU1} = \Omega_{MU1} + 1$
7. Set $\Omega_{MU2} = \Omega_{MU2} - 1$
8. Go to 15

MU1 and MU2 are the indexes of randomly selected two manufacturing units. We increase the production of first manufacturing unit by one unit, if possible, and reduce the production of second unit by one unit

9. Select a region Z randomly
10. Generate randomly *r1* (retailer) belongs to region Z
11. Generate randomly *r2* (retailer) belongs to region Z such that $\overline{d_{Zr2}}$ >0
12. If (r1=r2) go to 10
13. Set $\overline{d_{Zr1}} = \overline{d_{Zr1}} + 1$
14. Set $\overline{d_{Zr2}} = \overline{d_{Zr2}} - 1$
15. End.

r1and r2 are the indexes of two retailers in the region Z. We increase the average demand by one unit of retailer 1 and decrease the demand of retailer 2 by same quantity.

4.3 Simulated annealing

In this section, we first explain the simulated annealing algorithm for minimization problem and the use of this algorithm for our problem.

Let T_i be the initial temperature, R_t the cooling rate, T_f the final temperature also known as frozen temperature, T_m the current temperature and *MAXCOUNT* the maximum allowed move for which solution has not been improved i.e. the temperature will changed after these number of moves.

Step 1. Find the initial feasible solution S. Set initial temperature T_i=T_0 and *Count*=0;

Step 2. Compute $TC(S)$ and set $S_{Opt} = S$

S is the feasible solution of problem. TC(S) represents the criterion value of solution set S. In our case it is the total cost incurred in all activities.

Step 3. Search the new NS. Let it be $S^{'}$ be these NS.

The method already explained in section 4.2.

Step 4. Set $\Delta = TC(S^{'}) - TC(S)$

4.1 If $\Delta \le 0$, then accept this solution and set $S = S^{'}$

else

set $S = S^{'}$ with probability $\exp(-\Delta / T_m)$;

4.2 If $TC(S^{'}) < TC(S_{Opt})$ then set $S_{Opt} = S$

4.3 Set *Count=Count+1;*

Step5 If *Count>MAXCOUNT*

5.1 $T_m = R_t T_m$ and *count* =0;

5.2 if $T_m < T_f$ Stop

else go to step 3.

In this problem, the objective is to maximize the profit. Mathematically,

$$Max\ TP = BN(T) - CS\left(\{y_{ij}\}_{i=1,2,..r;j=1,2,...,z_i}, T\right) - \mathrm{CB}(i = 1,..n; k = 1,..m) - MAN(\{\Omega_k\} k = 1,...,m, T) - CM\ (T) \qquad (14)$$

or

$Max\ TP = BN(T) - IE$

where $BN(T)$ is the expected revenue as explained in "Sell" activity and *IE* is the net expenses and investments during the project horizon in "Store", "Buy", "Make" and "Move" activities. Equation (14) shows that total profit *TP* is the difference between expected revenue and the total expenses made in all activities.

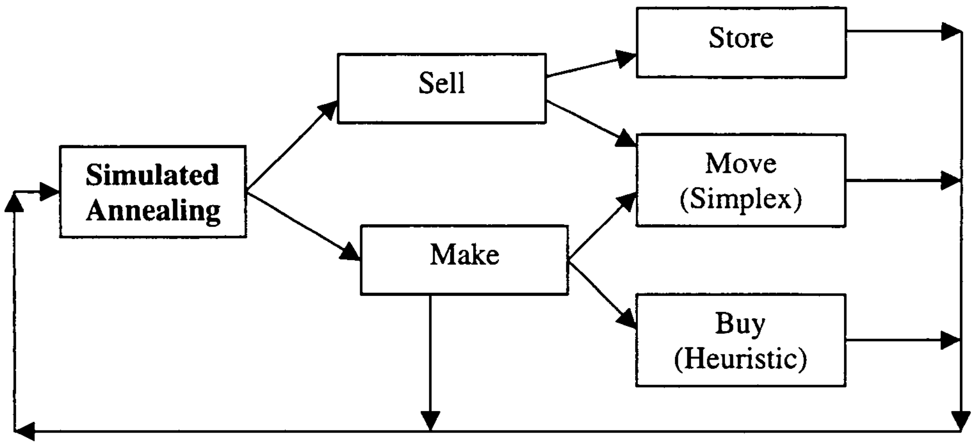

Fig 2: Activities flow chart

As explained in the section 3, that as soon as the production of manufacturing unit is decided, the optimal value of other activities could be computed easily. The solution approach could be best explained by fig 2. In the above algorithm, we change the production of manufacturing units and retailer's average demand by using *NS* (explained before), "Move" & "Buy" activities are computed by simplex algorithm and heuristic respectively. The output of all three activities (total cost) *TA,* corresponding to new solution *S'*, is used as the objective function value in SA.

5. Numerical example

In this section we illustrate a solution approach with a randomly generated example. The parameters concerning different activities are summarized in following tables:

5.1 Buy

Eight providers are listed for feeding the four selected manufacturing units. The cumulated demand of all zones is 370 units in each elementary period.

The costs functions are given as follows:

$$K(Xij) = A_{ij} + B_{ij} X_{ij}$$

$$i=1,2..8 \text{ (index of providers)}$$

$$j=1,2,3,4 \text{ (index of manufacturing units)}$$

The value of A_{ij}, B_{ij}, maximum capacity of provider and lower limit (m_{ij}) are tabulated in Table 1.

Table 1: Parameters of cost functions, provider's capacity and lower limit

Provider No. (i) (Capacity)	Manufacturing unit 1			Manufacturing unit 2			Manufacturing unit 3			Manufacturing unit 4		
	m_{i1}	A_{i1}	B_{i1}	m_{i2}	A_{i2}	B_{i2}	m_{i3}	A_{i3}	B_{i3}	m_{i4}	A_{i4}	B_{i4}
1. (80)	10	10	0.25	10	40	1.11	10	50	0.18	10	50	0.13
2. (180)	10	60	0.8	10	15	0.19	10	45	0.7	10	40	0.13
3. (120)	10	50	0.8	10	10	0.32	10	19	0.22	10	50	0.13
4. (80)	10	10	0.5	10	10	1.1	10	50	0.1	10	50	0.13
5. (180)	10	35	0.8	10	15	0.9	10	45	0.7	10	62	0.17
6. (120)	10	30	0.8	10	18	0.2	10	10	0.22	10	50	0.13
7. (180)	10	30	0.8	10	25	0.9	10	45	0.7	10	42	0.13
8. (120)	10	53	0.8	10	18	0.2	10	17	0.2	10	19	0.13

Figures in parenthesis show the maximum capacity of providers.

5.2 Sell

The selling price of an items are listed in table 2. the selling cost is generated randomly. Average demand of regions and retailers and standard deviation of regions are presented in table 3.

Table2: Selling cost of an Item in different regions

Regions (i)	b_{i1}	b_{i2}	b_{i3}	b_{i4}	b_{i5}
1	262	238	255	221	240
2	245	249	229	233	235
3	226	266	252	248	232
4	262	266	263	248	257
5	262	225	233	224	263
6	253	242	237	239	266

Table3: Standard deviation and average demand of regions and average demand of retailers

Regions (i)	σ_i	$\overline{d_i}$	$\overline{d_{i1}}$	$\overline{d_{i3}}$	$\overline{d_{i3}}$	$\overline{d_{i4}}$	$\overline{d_{i5}}$
1	12	75	12	11	9	24	19
2	14	45	5	15	13	3	9
3	12	86	28	20	20	15	3
4	18	56	16	8	12	7	13
5	16	58	8	14	11	7	18
6	14	50	5	10	5	26	4

5.3 Store

For the store activity, we assumed that Inventory holding cost and lost sell costs are same for all retailer stores.

$h_{jk} = 0.85$

$v_{jk} = 6.0$ where $j = 1,2,..r$, $k = 1,2,..z_j$.

Other parameters are tabulated in table 3.

5.4 Move

In this example we assumed that the vehicle capacity is same in all regions. The new vehicle cost is summarized in table 4 and transportation cost, available capacity are summarized in table 5.

Table 4: New vehicle cost in the region of manufacturing unit

Manufacturing Unit	New vehicle cost
1	100
2	90
3	120
4	80

Abbreviations TC and AC are used to represent per unit transportation cost and available transportation capacity respectively.

Table 5: Parameters concerning "Move" activity

M-Unit Retailers	M-Unit 1		M-Unit 2		M-Unit 3		M- Unit 4	
	TC	AC	TC	AC	TC	AC	TC	AC
R_{11}	0.1	10	0.12	0	1.1	10	0.32	0
R_{12}	0.21	10	0.41	5	0.11	10	0.41	5
R_{13}	0.12	15	0.12	5	0.22	10	0.42	5
R_{14}	0.11	20	0.11	5	0.41	10	0.49	5
R_{15}	0.21	15	0.41	10	0.31	15	0.41	5
R_{21}	0.11	0	0.51	0	0.47	0	0.11	0
R_{22}	0.21	5	0.21	5	0.41	10	0.51	5
R_{23}	0.22	5	0.22	5	0.22	5	0.22	10
R_{24}	0.21	5	0.21	5	0.61	10	0.28	10
R_{25}	0.21	10	0.21	5	0.21	5	0.21	5
R_{31}	0.19	0	0.69	5	0.29	10	0.69	0
R_{32}	0.49	5	0.29	5	0.39	10	0.29	5
R_{33}	0.19	5	0.69	5	0.19	15	0.69	5
R_{34}	0.19	5	0.59	0	0.49	0	0.19	0
R_{35}	0.39	5	0.39	5	0.39	15	0.29	5
R_{41}	0.19	5	0.19	10	0.19	5	0.19	0
R_{42}	0.49	5	0.39	10	0.49	5	0.49	5
R_{43}	0.19	5	0.19	15	0.29	5	0.89	5
R_{44}	0.19	0	0.19	20	0.39	5	0.39	5
R_{45}	0.39	5	0.39	15	0.39	10	0.39	10
R_{51}	1.1	10	0.21	0	1.21	5	0.16	0
R_{52}	0.11	10	0.21	10	0.11	5	0.21	5
R_{53}	0.12	15	0.12	10	0.12	5	0.22	5
R_{54}	0.41	20	0.21	20	0.41	5	0.21	5
R_{55}	0.31	15	0.21	15	0.31	5	0.41	5
R_{61}	0.41	0	0.69	10	0.48	5	0.69	5
R_{62}	0.61	10	0.29	10	0.61	5	0.49	5
R_{63}	0.22	15	0.69	15	0.22	5	0.69	5
R_{64}	0.41	20	0.29	20	0.41	0	0.49	0
R_{65}	0.21	15	0.29	15	0.21	5	0.79	5

5.5 Make:

We assumed six type of resources in each manufacturing unit. The parameters related to make activity are summarized in table 6.

Table 6: Parameters concerning "Make" activity

Resource type		Manufacturing unit 1	Manufacturing unit 2	Manufacturing unit 3	Manufacturing unit 4
1	Available Resources	4	2	2	1
	Processing Capacity	2	2	2	2
	Processing cost	0.11	0.61	0.11	0.91

	Procurement cost	20	50	24	80
2	Available Resources	1	5	1	1
	Processing Capacity	1	1	1	1
	Processing cost	0.17	0.67	0.97	0.97
	Procurement cost	19	59	19	69
3	Available Resources	4	3	3	2
	Processing Capacity	1	1	1	1
	Processing cost	0.12	0.52	0.12	0.92
	Procurement cost	20	29	19	29
4	Available Resources	3	3	3	1
	Processing Capacity	5	5	5	5
	Processing cost	1.11	1.11	0.11	1.71
	Procurement cost	47	37	27	47
5	Available Resources	1	2	1	1
	Processing Capacity	2	2	2	2
	Processing cost	0.05	0.25	1.15	0.65
	Procurement cost	48	98	18	98
6	A-Resources	1	1	1	1
	Processing Capacity	4	4	4	4
	Processing cost	1.09	0.09	0.09	0.99
	Procurement cost	24	65	12	95

5.6 Result

As explained earlier in section 3 that "Store" and "Sell" are fixed throughout the project span and not been affected by other three activities. so, we didn't included in SA. We ran this example with initial temperature of 100 and cooled up to 1 with cooling rate of 0.99 and

MAXCOUNT of 10. The convergence of SA search is displayed in Fig3 and the end results of all activities are summarized hereafter.

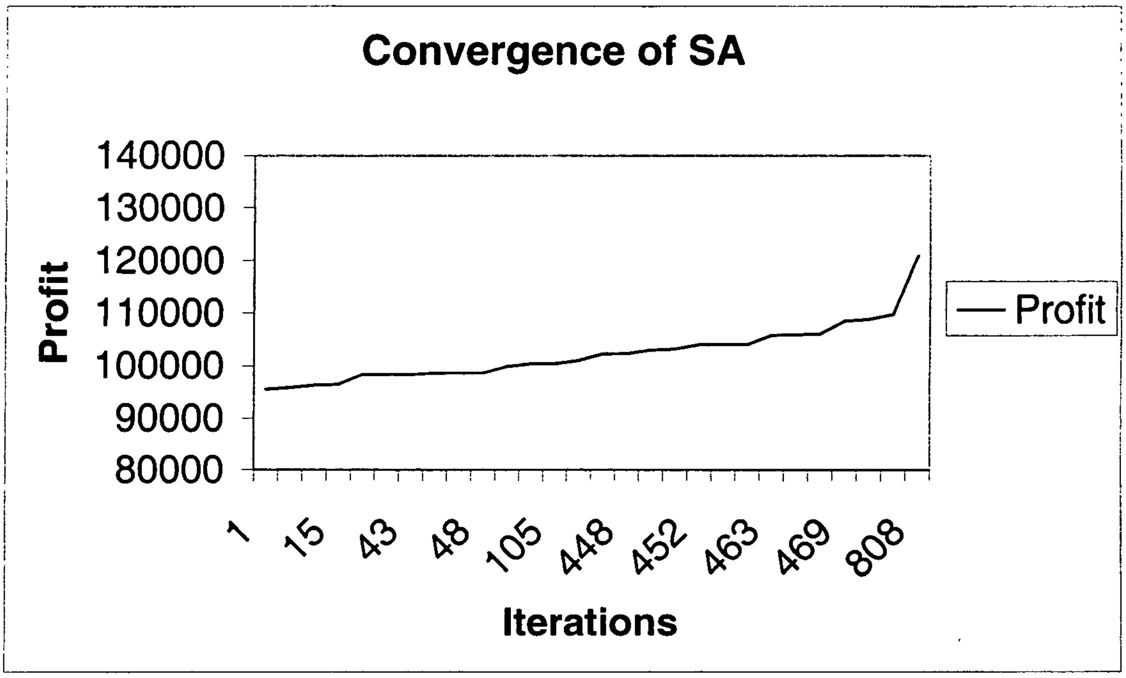

Fig 3: Convergence graph of simulated annealing

The target quantity of retailers is represented in Table 7. The values shown in table 9 are the greatest integer of calculated target quantity. The expected cost of store activity is calculated on the basis of tabulated values.

Table 7: Target quantity of retailers

$R_{11} = 6$	$R_{12} = 6$	$R_{13} = 5$	$R_{14} = 14$	$R_{15} = 11$
$R_{21} = 2$	$R_{22} = 4$	$R_{23} = 4$	$R_{24} = 2$	$R_{25} = 3$
$R_{31} = 18$	$R_{32} = 12$	$R_{33} = 12$	$R_{34} = 9$	$R_{35} = 2$
$R_{41} = 4$	$R_{42} = 2$	$R_{43} = 3$	$R_{44} = 2$	$R_{45} = 3$
$R_{51} = 3$	$R_{52} = 4$	$R_{53} = 3$	$R_{54} = 2$	$R_{55} = 5$
$R_{61} = 2$	$R_{62} = 3$	$R_{63} = 2$	$R_{64} = 10$	$R_{65} = 2$

Results of Buy activity are summarized in Table 8. It shows the quantity to be purchase from various providers.

Table 8: Quantity provided by providers to various manufacturing units

Unit	Provider1	Provider2	Provider3	Provider4	Provider5	Provider6	Provider7	Provider8
1	80	0	0	39	0	0	0	0
2	0	0	0	0	0	97	0	0
3	0	0	37	0	0	0	0	0
4	0	0	0	0	0	0	0	117

Result of "Move" activity is summarized in table 9.

Table 9 Result of "Move" activity

M-Units → Retailers ↓	Manufacturing unit 1	Manufacturing unit 2	Manufacturing unit 3	Manufacturing unit 4
R_{11}	10	0	0	0
R_{12}	10	0	0	0
R_{13}	15	0	0	0
R_{14}	20	5	0	0
R_{15}	11	0	0	4
R_{21}	0	0	0	5
R_{22}	5	5	0	5
R_{23}	0	0	0	10
R_{24}	0	0	0	10
R_{25}	0	0	0	5
R_{31}	0	5	0	15
R_{32}	5	5	10	0
R_{33}	5	0	10	0
R_{34}	5	0	0	15
R_{35}	0	0	11	0
R_{41}	5	0	0	5
R_{42}	0	10	0	2
R_{43}	0	0	0	14
R_{44}	0	8	0	0
R_{45}	0	2	0	10
R_{51}	8	0	0	0
R_{52}	0	2	5	5
R_{53}	0	10	0	0
R_{54}	0	6	1	3
R_{55}	0	15	0	3
R_{61}	0	0	0	5
R_{62}	0	10	0	1
R_{63}	8	0	0	0
R_{64}	0	14	0	0
R_{65}	12	0	0	0

6. Conclusion

This paper presents an approach to optimize the strategic model of supply chain. Optimizing all activities simultaneously is a NP-hard problem because of "Buy" activity that uses concave costs and is similar to the concave cost transportation problem. It has been already proved by researchers (Larsson et al.,1994) that concave cost transportation problems belongs to NP-hard category.

Our results are obtained using SA which, in turn, activating heuristic and simplex algorithm in each iteration. It is well known that the result of evolutionary algorithms also depends upon the parameter settings and initial solutions. We run the experiments several time to set good parameter and tested the final result with different initial solutions, but better result could be expected with other parameters and initial solutions. The potential of other algorithm in this respect such as Genetic algorithms and Tabu could not be ignored, may lead us to better results.

Some researchers proposed SA and threshold accepting (Shangyao 99) for concave cost network problem and result could be improved by using SA in place of heuristic.

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Appendix A

Heuristic 1 (N provider and single manufacturing unit)

The notations are given in the previous section. We assume that none of the providers are such that $A<m_i$, as these providers would not be able to meet the demand. Furthermore, if any provider is such that $M_i>A$, we will assume $M_i=A$ for our algorithm. We also assume that the providers are arranged in the increasing order of the $\frac{k_i(M_i)}{M_i}$, $i=1,2..n$ i.e.

$$\frac{k_1(M_1)}{M_1}\leq\frac{k_2(M_2)}{M_2}\leq\frac{k_3(M_3)}{M_3}\leq\ldots\ldots\frac{k_n(M_n)}{M_n}$$

Step1

1. For $j=1$ to n do
   1.1. If $A\geq M_j$ then
      1.1.1. Set $x_j=M_j$
      1.1.2. Set $A=A-M_j$
      1.1.3. If ($A>0$ and $j=n$) then there is no solution. Stop.
      1.1.4. If ($A=0$) then optimal solution is obtained, otherwise go to 2
   1.2. If ($A<M_j$) then
      2.2.1. Set $E_0=(1,2\ldots j\text{-}1)$
      2.2.2. go to 3
      In the current loop we assign the maximum possible quantity to the providers taken in increasing order of their cost per unit, if they can deliver the maximum possible quantity
2. End of loop j.

Step2

3. For $i=1$ to n do $x_i^*=x_i$
   We preserve the values of the variables at the end of first step.
4. Set $E_1=\{s\,/\,s\in\overline{E_0}\cap(k\,/\,A\leq M_k\,,k=1..n)\}$
   E_1 is the set of indexes of the providers which has not been allotted yet and whose maximum capacity is greater than or equal to the remaining demand.
5. Set $E_2=\{t\,/\,t\in\overline{E_0}\cap(k\,/\,A>M_k\,,k=1..n)\}$

E_2 is the set of indexes of the providers which has not been allotted yet and whose maximum capacity is less than the remaining demand.

6. For every $s \in E_1$.

6.1. For i=1 to n do $x_i = x_i^*$

6.2. If $A < m_s$ then go to 6.7

6.3 . Set $x_s = A$

6.4. Set $d = M_s - A$

6.5. For j=1 to n

(**Note**: *Do not consider the providers for which* $x_i = 0$ *in the next step)*

6.5.1. For i=1 to n

$$d_i = \frac{k_i(M_i)}{M_i} \qquad \text{if } d > M_i$$

$$d_i = \frac{k_i(M_i) - k_i(M_i - d)}{(M_i - d)} \qquad \text{if } m_i \le M_i - d$$

$$d_i = \frac{k_i(M_i) - k_i(M_i - m_i)}{(M_i - m_i)} \qquad \text{if } m_i > M_i - d$$

$$d_s = \frac{k_s(M_s) - k_s(x_s)}{(M_s - x_s)}$$

$$d_i = -1 \qquad \text{if } x_i = 0$$

(Hereafter, we will refer to d_i as the ratio)

6.5.2. Arrange all the provider in the decreasing order of the d_i.

We denote the rank of the ratios by j=1…n. p(j) gives the index of the provider whose ratio rank is j. As a consequence p(1) gives the provider's index of the highest ratio.

6.5.3. If $d_{p(1)} < d_s$ then go to 6.15

If this inequality do not hold, then it is possible to reduce $x_{p(1)}$ to 0 by increasing the value of the variable having a ratio less than the ratio of $x_{p(1)}$. (See Result 2).

6.5.4. If $d < M_{p(1)}$ go to 6.5.10

6.5.5. Set $x_{p(1)} = 0$

6.5.6. Set d=d-$M_{p(1)}$

6.5.7. Set $x_s = x_s + M_{p(1)}$

6.5.8. If x_s=M_s go to 6.15

In this case we apply the previous remark and reduce $x_{p(1)}$ to zero by increasing the x_s having a ratio less than the ratio $x_{p(1)}$.

6.5.9. Go to 6.6

6.5.10. Set $x_{p(1)} = x_{p(1)} - \min(x_{p(1)} - m_{p(1)}, d)$

6.5.11. Set d=d- $\min(x_{p(1)} - m_{p(1)}, d)$

6.5.12. Set $x_s = x_s + \min(x_{p(1)} - m_{p(1)}, d)$

6.5.13. If x_s=M_s go to 6.15

In this case we cannot reduce $x_{p(1)}$ to zero. Thus we reduce it as much as possible if this reduce the total cost.

6.6. End of j loop.

6.7. Set x_s=m_s

A is less than m_s. Nevertheless, we assign, m_s to x_s and will take the missing quantity (m_s-A) from the providers already selected, if this improve the solution.

6.8. Set D=m_s−A

Missing quantity is denoted by D

6.8.1. For i=1 to p

$$d_i = \frac{k_i(M_i)}{M_i} \qquad \text{if } D>M_i$$

$$d_i = \frac{k_i(M_i)-k_i(M_i-D)}{(M_i-D)} \qquad \text{if } m_i \le M_i-D$$

$$d_i = \frac{k_i(M_i)-k_i(M_i-m_i)}{(M_i-m_i)} \qquad \text{if } m_i > M_i-D$$

$$d_i = -1 \qquad \text{if } x_i = 0$$

6.9. Arrange all providers of E_0 in the decreasing order of their ratio.

We denote the ranks of the ratios by j=1...p. $v(j)$ gives the index of the provider whose ratio rank is j. As a consequence $v(1)$ gives the provider's index of the highest ratio. p is the total elements in E_0.

6.10. For $k=1$ to p

6.10.1. If $D<x_{v(k)}$ then go to 6.10.4

6.10.2. Set $D=D-x_{v(k)}$

6.10.3. Set $x_{v(k)}=0$ go to 6.11

6.10.4. Set $shift=\min(x_{v(k)}-m_{v(k)},D)$

6.10.5. Set $x_{v(k)}=x_{v(k)}-shift$

6.10.6. Set $D=D-shift$

In this loop we try to compensate the missing value D by taking an equal quantity from the variables that have a maximum derivative. Indeed, this does not guarantee that the increase of the cost due to the increase of x_s *will be less than the decrease of the cost due to the decrease of the* $x_{v(k)}$ *values.*

6.11. End of loop k.

6.12. $d=M_s-x_s$

6.13. For $j=1$ to n

(**Note**: *Do not consider the providers for which* $x_i=0$ *in the next steps)*

6.13.1. For $i=1$ to n

$$d_i=\frac{k_i(x_i)}{x_i} \qquad \text{if } d>x_i$$

$$d_i=\frac{k_i(x_i)-k_i(x_i-d)}{(x_i-d)} \qquad \text{if } m_i\le x_i-d$$

$$d_i=\frac{k_i(x_i)-k_i(x_i-m_i)}{(x_i-m_i)} \qquad \text{if } m_i>x_i-d$$

$$d_s=\frac{k_s(M_s)-k_s(x_s)}{(M_s-x_s)}$$

$$d_i=-1 \qquad \text{if } x_i=0$$

6.13.2. Arrange all the providers in the decreasing order of the d_i.

We denote the rank of the ratios by j=1…n. p(j) gives the index of the provider whose ratio is at rank j. As a consequence p(1) gives the provider's index of the highest ratio.

6.13.3. If $d_{p(1)}<d_s$ then go to 6.13.9

If this inequality do not holds, then it is possible to assign 0 to $x_{p(1)}$ by increasing the values of the variables having a ratio less than the ratio of $x_{p(1)}$ (See Result 2).

6.13.4. If $d<M_{p(1)}$ go to 6.13.10

6.13.5. Set $x_{p(1)}=0$

6.13.6. Set $d = d - M_{p(1)}$

6.13.7. Set $x_s = x_s + M_{p(1)}$

6.13.8. If $x_s = M_{p(1)}$ go to 6.15

In current loop we apply the previous remark and reduce $x_{p(1)}$ to zero by increasing the x_s having ratio less than the ratio of $x_{p(1)}$.

6.13.9. Go to 6.15

It shows we can not reduce other variables and by increasing x_s as it increase the criterion.

6.13.10. Set $x_{p(1)} = x_{p(1)}$ - $\min(x_{p(1)} - m_{p(1)}, d)$

6.13.11. Set $d = d - \min(x_{p(1)} - m_{p(1)}, d)$

6.13.12. Set $x_s = x_s$ - $\min(x_{p(1)} - m_{p(1)}, d)$

6.13.13. If $x_s = M_{p(1)}$ go to 6.15

In this case, we cannot reduce $x_{p(1)}$ to zero. Thus we reduce it as much as possible, if this reduce the total cost (See result 2)

6.14. End of *j* loop.

6.15.Compute the total cost for this combination. If this combination is better than previous one, then replace the previous combination by new one.

7.End of *s* loop.

Step 3

8.Assume that E_2 contains q elements. We number the elements 1,2,…,q and the index of the elements are *g(1),g(2),…g(q)*. The order of elements are random.

For *i=1 to q*

8.1 If $i = 1$ go to 8.4

8.2 Set $x_{g(i-1)} = 0$

Remove this index i.e. g(i-1) from the E_0 as E_0 is the set of provider's indexes that are providing their maximum quantity.

8.3 Set $A = A + M_{g(i-1)}$

8.4 Set $x_{g(i)} = M_{g(i)}$

Add this index i.e. g(i) from the E_0 as E_0 is the set of provider's indexes that are providing their maximum quantity.

8.5 Set $A = A - M_{g(i)}$

8.6 Go to 3.

End of i loop.

E_2 contains the indexes of providers whose M_i is less than the remaining demand. We select these providers I one by one, allocate M_i to the manufacturing unit and reduce the demand accordingly. Now, we rearrange E_0, E_1 and E_2 for the remaining demand. We will repeat step 2 with the new sets E_0, E_1 and E_2.

Heuristic 2 (multi provider and multi manufacturing unit)

Notations used in Algorithm:

P	Set of Providers.
p	Index of provider
D	Set of manufacturing unit
d	Index of manufacturing unit
M_p	Maximum capacity of provider p
A_d	Demand of manufacturing unit d
m_{pd}	Minimum quantity the provider p is prepared to sell to unit d.
T_p	Number of providers
T_m	Number of manufacturing units

$NPSM\_Q(A_d,p)^3$ Algorithm that return the quantity taken by unit d from provider p by applying NPSM. The quantity taken from the other providers are ignored.

$NPSM\_C(A_d)^4$ Algorithm that returns the optimal cost incurred for ordering quantity A_d considering all the available providers by applying NPSM.

x_{ij} *Array to store the quantity of raw material provided by provider* p *to manufacturing unit* j.

Assumption:

$\sum_{p=1}^{n} M_p \geq \sum_{d=1}^{m} A_d$, which means that the total quantity the providers are able to deliver should be greater than or equal to the total quantity required by the manufacturing units, otherwise there is no solution to the problem.

Algorithm

Step 1

Initialize x_{ij} to zero.

1. Set $p=0$

   1.1. Set $p=p+1$ If $p>T_p$ Stop

   1.2. If $M_p=0$ go to 1.1

   Above step select the first provider with positive supplying capacity.

2. Set d=0

   d is the counter related to manufacturing units.

3. Set $d=d+1$

   3.1. If $A_d=0$ and $d<T_m$ then *go to 3*

   A_d *is the demand of manufacturing unit d.*

   3.2. If $d>T_m$ then go to 1.1

   3.3. If $p>T_p$ Stop.

   The above steps select a manufacturing unit and a provider with potential demand and capacity. Loop 3 is frequently called by step 4.6.

4.Set $already\_taken=x_{pd}$

   4.1. Set $A_d=A_d + already\_taken$

   4.2. $M_p=M_p + already\_taken$

[3] [2] NPSM_Q and NPSM_C are the name given to NPSM algorithm, when it returns quantity and cost respectively.

In the above step 4, we temporarily return the already assigned quantity to the selected provider by the selected manufacturing unit, if any. Since non assignment may hide better solutions.

4.3.Set $Q_1=NPSM\_Q(A_d,p)$

Q_1 is the quantity returned by the NPSM algorithm. It is the quantity provided by provider p, if unit d ordered quantity A_d. Remember that NPSM is taking all provider into account for calculating the cheapest cost. We are only interested in the quantity supplied by the current selected provider p.

4.4.Set $A_d=A_d$ *-already_taken*

4.5.Set $M_p=M_p$ *- already_taken*

4.6.If Q_1 = already_taken then go to 3

If already_taken=0 and Q=0, then the selected manufacturing unit is not interested in this provider. If already_taken >0 and Q_1=already_taken, then this unit still is demanding the same quantity. So we do not require any decision whether this quantity has to be supplied or not as it is already allotted. We select the next unit.

Above steps select a manufacturing unit that required provider p for optimum allocation of its demand.

4.7.Set *unit=d*

4.8.Set *Quantity=Q_1*

4.9.Set *Already_taken_preserve=already_taken*

4.10. Set *diff=0*

In steps 4.7 and 4.9, we stored the index of the selected manufacturing unit and quantity Q_1 in temporary variables for further reference. Here, we assume that provider p is supplying quantity Q_1 to unit d.

Step 2

5. Set *d=d+1*

In step 2, we check if the rest of manufacturing units find this provider suitable.

6. If $d>T_m$ go to 15.
7. If $A_d=0$ *go to 5*
8. Set *already_taken=x_{pd}*
   8.1.Set $M_p=M_p$ *+ already_taken*
   8.2.Set $A_d=A_d$ *+ already_taken*
9. Set $C_1=NPSM\_C(A_d)$

C_1 is the cheapest cost for providing quantity A_d to manufacturing unit d if the current selected provider p is available for this unit.

10. Set $Q' = NPSM\_Q(A_{d,} p)$
11. Set $M_p = M_p - Quantity$

    We have reduced the provider's p capacity temporarily, just for checking its implication in the supply of other manufacturing units.

12. Set $C_2 = NPSM\_C(A_d)$

    C_2 is the cost incurred, if current provider's p capacity is reduced by 'Quantity'. If there is no solution, then assign very high value to C_2.

13. Set $M_p = M_p + Quantity$
    - 13.1. Set $A_d = A_d$ - *already_taken*
    - 13.2. Set $M_p = M_p$ - *already_taken*

    We now reset M_p and A_d to their original values for further calculation.

    (Remember that we M_p by "Quantity", A_d and M_p both by "already_taken" in steps 8, 11)

14. If $C_2 - C_1 > diff$
    - 14.1. Set *unit=d*
    - 14.2. Set $Quantity = Q'$
    - 14.3. Set $diff = C_2 - C_1$
    - 14.4. *Already_taken_preserve=already_taken*
    - 14.5. Set $d=0$
    - 14.6. Go to 5

    (End of manufacturing loop)

    From steps 5 to 14 we have selected a manufacturing unit that has an utmost requirement for provider p.

15. Set $x_{p\ unit} = Quantity$
16. Set $M_p = M_p$- *Quantity + already_taken_preserve*
17. Set $A_{unit} = A_{unit}$ – *Quantity + already_taken_preserve*

    In steps 15 to 17 we have assigned the selected provider to the selected (in step 14) manufacturing unit and updated the other variables accordingly.

18. Go to 1.

End of provider

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